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Visualizing pre-service biology teachers´ conceptions about population dynamics in ecosystems

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Abstract
The Balance of Nature (BoN) metaphor leads to various naïve conceptions about ecosystem dynamics that do not address current scientific theories adequately. An appropriate alternative is the Flux of Nature (FoN) metaphor. Approaches to conceptual development in science education aim for learners to develop scientifically adequate conceptions rather than maintain naïve conceptions. Our goal was to investigate naïve BoN conceptions and their sources with the method of visualization. Therefore, we examined pre-service biology teachers' (*n* = 26) conceptions about ecosystem dynamics by asking them to draw and explain line graphs to predict the development of a population. Graphs and explanations were analyzed with qualitative content analysis and assigned into categories related to either the BoN or the FoN metaphor. The majority of the graphical predictions were found to be in line with the BoN metaphor, which replicates the findings of previous studies. Additionally, the method of visualization shows that a common model used in ecology that is often presented in biological textbooks influenced the predictions made by our participants. When used uncritically, this model can support naïve BoN conceptions. Thus, our results suggest that the use of scientific models and pedagogical materials may influence conceptual development in this context.

Keywords
Conceptions in ecology; visualization; assessment of conceptions; balance of nature metaphor

1. Introduction

When thinking about ecosystems and whether they are dynamic or stable, the so-called Balance of Nature metaphor (BoN) is often invoked and leads to various naïve conceptions that are not in line with current scientific theories (Hovardas & Korfiatis, 2011; Zimmerman & Cuddington, 2007). Conceptual development research assumes that learners'[1] (mostly naïve) conceptions are derived from everyday life experiences (Duit & Treagust, 2003). In previous studies (Ergazaki & Ampatzidis, 2012; Sander, Jelemenská & Kattmann, 2006; Zimmerman & Cuddington, 2007) learners externalized their conceptions about ecosystems and the BoN metaphor verbally in interviews or questionnaires. Assessing conceptions by visualization can provide additional information and may complement students´ verbal expressions (Chang, Quintana & Krjcik, 2014; Kern, Wood, Roehrig & Nyachwaya, 2010). There is currently no research on conceptions of ecosystem dynamics using this kind of assessment. Individual conceptions about population dynamics that are graphically externalized may

[1] *Learners* are defined as every person that learns within an educational institution independent of their age group. In the case of this study, we focused on pre-service biology teachers at the end of their studies as learners with a high biological prior knowledge to get insights into their conceptions, with which they are going to teach high-school students.

be strongly influenced by representations commonly used in educational settings, such as line graphs in textbooks (Roth, Bowen & McGinn, 1999).

2. Theoretical Background

The Balance of Nature (BoN) metaphor assumes that nature is stable, harmonic, and self-regenerating (Cuddington, 2001; Ergazaki & Ampatzidis, 2012; Ladle & Gillson, 2009). Scientific theories that describe stable equilibrium states in ecosystems that have been used in biological science are also connected to this metaphor (Cuddington, 2007; Ladle & Gillson, 2009; Wu & Loucks, 1995). However, since the 1970´s a paradigm shift in ecology has focused on hierarchical patch dynamics, characterizing ecosystems with multiple equilibria and instability (Pickett, Kolasa & Jones, 2007; Wu & Loucks, 1995). For educational purposes, therefore, naïve BoN conceptions need to be replaced by a Flux of Nature (FoN) metaphor (Ladle & Gillson, 2009; Pickett et al., 2007). Table 1 shows core conceptions with a focus on population dynamics resulting from the two metaphors.

Table 1. Comparison of core conceptions about population dynamics based on either the BoN or FoN metaphor

Balance of Nature (BoN)	Flux of Nature (FoN)
There is one balanced state of nature in an ecosystem.	There is more than one balance point with different consequences for ecosystem and population dynamics in an ecosystem.
Population numbers are well-balanced based on harmonic relations between species.	Population numbers can change based on mutual relations between nature and society.
Disturbances in an ecosystem are unnatural and caused by humans (e.g. extinction of a species).	Balance and imbalance in an ecosystem can be the result of natural and human causes, where the extinctions of species can be a natural process.

Zimmerman and Cuddington (2007) found that conceptions related to the BoN metaphor were held by biology students even after taking a university-level class in ecology aimed at promoting conceptions in line with the FoN metaphor. Consequently, BoN-related naïve conceptions seem to be resistant to instruction, which presents a challenge for biology educators. BoN-associated conceptions assume stable, harmonic, or cyclic development of populations in an ecosystem and are supported by the model established by Lotka and Volterra in 1925/26 (Cuddington, 2007). This model includes mathematical equations that are used in ecology for modelling predator-prey relations over time. However, these equations were derived from theories about physical chemistry with the assumption of a closed system, but real ecological systems are open systems (Cuddington, 2007; Hall, 1988). Additionally, external representations of population dynamics such as those found in textbooks or scientific texts often have the form of Cartesian line graphs (Roth et al., 1999). Line graphs representing the Lotka-Volterra model are commonly used. If learners frequently encounter such representations along with a specific concept, it is likely that these will be internalized as mental representations associated with that concept (Al-Balushi, 2011; Ehrlén, 2009). We assume, therefore, that learners associate typical line graphs with population dynamics. Thus, the investigation of such external representations may provide additional insights into the underlying individual conceptions of BoN or FoN. Graphs that represent BoN include stable (linear-horizontal) and oscillating (fluctuation around a mean) graphs. In contrast, graphs that represent FoN include those that fluctuate chaotically, increase or decrease, or may reach zero to express the possibility of population extinction and characterize the instability and unpredictability of ecosystems.

To test these assumptions we investigated how pre-service biology teachers predict changes in a population in an ecosystem over time by drawing line graphs and how these drawings indicate the use of either the BoN or the FoN metaphor. Additionally, we explored whether they consider alternative hypotheses when asked to draw predictions for two different areas within a given ecosystem to assess if the theory of hierarchical patch dynamics that is included in the category of FoN-associated conceptions is used.

3. Research questions and hypotheses

When asked to predict population dynamics in two areas of an ecosystem, what types of line graphs do pre-service biology teachers draw? Do they use the BoN or the FoN metaphor to explain their graphs? We hypothesized that explanations consistent with the BoN metaphor would be positively related to linear-horizontal or oscillating graphs (H1). We hypothesized that explanations invoking the FoN metaphor would be positively related to a variety of graphs such as chaotic fluctuating or decreasing graphs (H2). Finally, because patch dynamics in ecosystems are not consistent with the BoN conception of one stable equilibrium state, we predicted that participants who draw FoN-associated graphs and use FoN explanations would be more likely to consider alternative predictions than participants who generate graphs and explanations associated with BoN conceptions (H3).

4. Method

4.1. Participants

Pre-service biology teachers (n = 26; 61.5% female) who participated were in the second semester of their Master of Education degree program at Humboldt-Universität zu Berlin (M age = 26.1 years, SD = 3.3). We chose these participants because they had completed at least one semester of an ecology class during their bachelor's degree. Because of the qualitative character of this study the sample size was chosen to reach a state of saturation and to provide information about a range of participant conceptions (Mason, 2010).

4.2. Test instrument

Participants completed a questionnaire containing a prediction task and an open-ended explanation task. An ecosystem in a national park was described which included a herbivore mammal (elk) and its natural predator (wolves). Next, information about the method of collecting population data was given along with the average elk population numbers for two previous years. Participants were asked to draw two line graphs to illustrate their assumptions about predicted changes in the elk population for the following ten years for two areas within the ecosystem. The two areas gave participants the opportunity to consider alternative hypotheses about the population dynamics. Next, they explained their line-graph predictions for both areas.

4.3. Data analyses

Data were analyzed in line with qualitative content analyses (Schreier, 2012). A theory-based coding system was developed deductively and refined inductively during the process of analyzing three example cases. The final coding system was used to analyze the remaining 24 cases using the coding software MAXQDA. A second coder re-coded 25% of the material using the same coding system. Interrater agreement (κ = .95) was very good (Wirtz & Caspar, 2007). Statistical relations between graph type codes and explanation codes were calculated in SPSS using Fischer´s exact test and phi correlation coefficient based on the nominal and dichotomous character of the data (Zöfel, 2011).

5. Results

Participants gave 74 explanations for their predictions of population change in the two areas of the ecosystem (n_{Area1} = 42, n_{Area2} = 32). Explanations were coded as *BoN consistent* or *FoN consistent* based on theory. In addition, two categories of explanation could not be defined unambiguously as BoN or FoN consistent (*Capacity limit*, n = 2; *Disturbances in general*, n = 2) and were not included in further data analyses. In total, participants drew 28 line graphs[2] per area. Figure 1 presents the frequency of types of line graphs drawn by participants. Furthermore, statistical relations between graph type and explanation type could be identified (Table 2).

5.1. Relations between BoN consistent explanations and graph type (H1)

The majority of explanations were based on ecological models describing predator-prey relations, such as the Lotka-Volterra-equations ($n_{\text{Lotka-Volterra}}$ = 27), where population numbers fluctuate slightly around a mean value. This explanation category was defined as BoN consistent and was positively related (r_{Phi} = .44; $p < .01$) to graphs of the oscillating type that were drawn by the majority of participants (n_{Area1} = 16, n_{Area2} = 14). Other categories of ex-

[2] One participant drew multiple graphs in each diagram for the two areas.

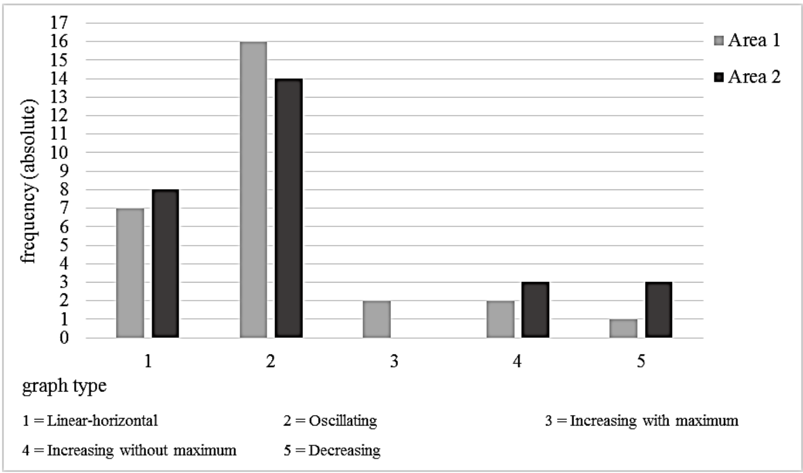

Figure 1. Absolute frequencies of types of line graphs drawn by the participants for predicting the population development in two areas of an ecosystem, N=26.

planations that were defined as BoN consistent were *Stable development* (n_{Stable}= 19), *Human-caused disturbances* ($n_{\text{Human-caused disturbance}}$ = 2) and *No disturbances expected* ($n_{\text{Disturbance not expected}}$ = 7). There was a positive relation between explanations describing ecosystem stability over time (r_{Phi}= .53; p < .001) or the non-expectancy of disturbances (r_{Phi} = .47; p < .01) and the graph type of linear-horizontal graphs (n_{Area1} = 7, n_{Area2} = 8) as prediction of elk population development.

5.2. Relations between FoN consistent explanations and graph type (H2)

Explanations stating possible interactions between the areas ($n_{\text{Interactions}}$ = 8) or explanations containing assumptions about a fluctuating change ($n_{\text{Fluctuating}}$ = 5) as well as naturally caused disturbances ($n_{\text{Naturally caused disturbance}}$ = 3) were defined as FoN consistent. The minority of participants generated FoN consistent explanations. Explanations of the category *Interaction between areas* were positively related to an oscillating graph type (r_{Phi} = .39; p < .05). Explanations of the *Fluctuating development* category were negatively related to oscillating graphs (r_{Phi} = -.38; p < .05) but positively related to the decreasing graph type (r_{Phi} = .69; p < .01). As with explanations, a minority of participants drew graph types that are consistent with FoN-related conceptions.

5.3. Relations between graph types and giving alternative hypotheses (H3)

The majority of participants (*n* = 21) drew the same graph type in both diagrams, therefore, making the same prediction for the two areas of the ecosystem. Five participants drew two different graphs to express alternative predictions for the elk population change. The relations between providing alternative predictions and making predictions in line with the BoN or FoN metaphor were estimated based on the results for the relations between graph types and explanations (see 5.1. and 5.2.). We found that BoN-related *oscillating graphs* were negatively related to giving alternative predictions (r_{Phi} = -.36, p < .05). In contrast, *decreasing graphs* were positively related to explanations in line with the FoN metaphor but also correlated positively with giving alternative predictions (r_{Phi} = .41, p < .05).

Table 2 Phi correlation coefficient between participants´ drawn types of line graphs and given explanations.

Graph type		Explanation
Linear-horizontal	r_{Phi}= *.53; p < .001*	Stable development
	r_{Phi} = *.47; p < .01*	No disturbance expected
Oscillating	r_{Phi} = *.44; p < .01*	Prey-predator relation/Lotka-Volterra
	r_{Phi} = *.39; p < .05*	Interaction between areas
	r_{Phi} = *-.38; p < .05*	Fluctuating development
Decreasing	r_{Phi} = *.69; p < .01*	Fluctuating development

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6. Discussion

A majority of participants drew linear-horizontal and oscillating line graphs that are consistent with BoN-related conceptions. Taking the corresponding explanations into account, these graph types were statistically related to typical conceptions that are connected to the BoN metaphor. Therefore, our first hypothesis is supported by these data. Interestingly, the most common explanations and graphs were influenced by the Lotka-Volterra population model. As participants were majors in biology education we assume knowledge of ecology and familiarity with the Lotka-Volterra model and the typical representation of the equations as fluctuating line graphs in most textbooks. In addition to the potential influence of external representations from pedagogical materials, the use of this model to make predictions may be related to participants' need to reduce the complexity of the presented problem and control for variables that are not as probable as simple prey-predator-relations, such as unexpected natural disturbances. The control-of-variables strategy is emphasized in science education and used to conduct controlled experiments to investigate causal relations (Schwichow, Croker, Zimmerman, Höffler, & Härtig, 2016). However, in the task we used, observational data from an uncontrolled system had to be predicted and, therefore, the use of idealized models such as Lotka-Volterra equations that exclude variables are legitimate for predictions of a systematic observation (Arnold, Wellnitz & Mayer, 2010; Norris, 1984), but should be used critically to describe the development of real and complex ecosystems (Cuddington, 2001). Furthermore, if used uncritically, Lotka-Volterra equations may promote belief in the BoN metaphor. Very few graphs drawn by participants were consistent with the FoN metaphor. Only decreasing graphs were statistically related to explanations in line with the FoN metaphor (H2). Results from the analysis of relations between the type of predictions (graph and explanation) and the predictions of alternative hypotheses show that participants using predictions based on the FoN metaphor gave alternative hypotheses (H3). This finding demonstrates on the one hand a scientifically adequate conception about ecosystem dynamics and on the other hand the openness to make predictions with different probabilities of occurrences in a complex system.

In summary, our results show how graphical externalization can provide an alternative insight into conceptions about ecosystem dynamics and how they may be influenced by representations typically used in biology education. Representations consistent with the BoN metaphor are prominently used in the media (Ladle & Gillson, 2009) and in school books (Korfiatis, Stamou & Paraskevopoulos, 2004) and thus may promote corresponding naïve conceptions. Furthermore, our results are consistent with previous findings about the stability and strength of naïve conceptions used to describe ecosystem dynamics, as these preservice biology teachers who were at the end of their biological studies used predictions and explanations related to the BoN metaphor. Moreover, their apparently distinct content knowledge but less adequate use of models may have a negative influence. Therefore, an awareness of the purposes and constraints of population models such as Lotka-Volterra, as well as characteristics of scientific observation as a method of inquiry should be promoted within educational contexts, especially if they are to be influential for conceptions about complex topics such as ecosystem dynamics. Otherwise, biology teacher candidates may inadvertently contribute to the naïve conceptions next generation of biology students.

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